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REPORT NO. B-5350-AS(b)

DATE 18 NOV 1944

SUBJECT

"DESIGN, CONSTRUCTION, AND TESTING OF A 6" VALVELESS-RESOJET"

BY

U. S. NAVAL ENGINEERING EXPERIMENT STATION
ANNAPOLIS, MARYLAND

E.E.S. REPORT No. B-5350-AS(b)

U.S.N.A.—2-12-43—5000

X-43725

CONFIDENTIAL

Serial No. EES-B-5350-AS(b)

NAVY DEPARTMENT

BUREAU OF AERONAUTICS

REPORT ON

"DESIGN, CONSTRUCTION, AND TESTING OF A 6" VALVELESS-RESOJET"

By

U. S. NAVAL ENGINEERING EXPERIMENT STATION
ANNAPOLIS, MARYLAND

NUMBER OF PAGES - Text 4; Plates 12.

AUTHORIZATION - BuAero. Conf. ltr. Aer-E-350-SL, F13-4(1) dated 21 May 1941.

DATE OF TEST - February to June, 1944

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X-43725

TABLE OF CONTENTS

AUTHORIZATION FOR TEST

1. This test was authorized by the Bureau of Aeronautics, letter Aer-E-350-S1-F-13-4(1) of 21 May 1941.

OBJECT OF TEST

2. The object of this work was to design, construct, and test a practical Valveless-Resojet motor operating on the principle of the intermittent firing of an atmospheric air-fuel mixture in a chamber to produce a high-velocity jet of the exhaust gases, which produces forward thrust on the motor by direct jet reaction.

SUMMARY

3. A 6" Valveless-Resojet motor was designed, constructed, and tested by this Station. This motor operates on the principle of the intermittent firing of an atmospheric air-fuel mixture in a chamber to produce a high-velocity jet of the exhaust gases which produces forward thrust on the motor.

4. The Valveless-Resojet (see Plate 1) consists of a combustion chamber, a nozzle pipe through which the exhaust gases leave the motor, an air-entrance duct in the front of the chamber, a means for injecting fuel and a means for igniting the fuel-air mixture in the combustion chamber.

5. In an earlier report by this Station entitled "Design, Construction and Testing of a 6" Resojet Motor", Serial No. EES-B-5350-AS(a), tests on a motor similar to the present motor were described. That motor operates on much the same principle, but employs mechanical, reed-type valves in the chamber head-plate to prevent loss of explosive energy in the forward direction. The present motor is, therefore, termed a "Valveless-Resojet" since its "valving" is accomplished acoustically, rather than mechanically.

6. The results of tests on the best motor shape tried are as follows (see Plates 2 to 7):

Approx. Air speed MPH	Net thrust LBS	Specific thrust lbs/lbs/sec.
340	10.5	954
420	13.5	835
480	Would not resonate properly.	

The fuel used in these tests was gaseous propane.

7. It is believed that Valveless-Resojets, in larger sizes, of course,

X-43725

would prove to be of great use in many applications which require a light-weight expendable jet propulsion unit or a light-weight, compact gas generator for driving turbines, etc.

DESCRIPTION OF EQUIPMENT

8. Plate 1 is a drawing of the best Valveless-Resojet tested. Plate 8 is a photograph of the motor completely assembled. The air intake pipe is made of 1-1/2" standard steel pipe, the annular head plate of 1/8" thick mild steel sheet, the combustion chamber of 6" standard steel pipe, the nozzle cone of 1/8" thick mild steel sheet, the nozzle pipe of 4" standard steel pipe, and the fuel supply tube (shown in Plates 8 to 10, protruding from the side of the air intake pipe) is of 3/8" copper tubing. Gaseous propane, the fuel in these tests, is delivered to the motor through this 3/8" tube and enters the air stream through 23 holes, No. 53 drill size, directed along radii of the air-intake pipe at its junction with the combustion chamber (see Plates 1, 9 and 10). The materials from which this motor was made would, of course, not be used if the motor were built as light-weight as possible. The motor described herein is, instead, a test stand model built for long operating life without cooling, and frequent and easy disassembly and modification. The propane used in these tests is purchased by the Navy in the slightly impure form known as "Pyrofax".

9. This type of jet propulsion device has been termed a "Resojet" by this Station since its operation depends upon the excitation of the natural fundamental frequency of the gas column in the tube by the intermittent force of the explosions therein. Referring to Plate 1, it can be seen that air travelling at high speed relative to the motor (as would be the case in operation on a fast-moving airplane) will enter the air-intake pipe and mix with gaseous propane as it enters the chamber. As the explosive mixture reaches the spark-plug, it is ignited, creating a high pressure within the chamber. This pressure surge moves both out the nozzle pipe and forward toward the air-intake pipe. First, this forward moving high pressure wave impedes the flow of propane which is delivered at constant pressure to the injection holes, and then enters the air-intake tube, stopping the air flow. As this pressure wave is dissipated, air and propane are again allowed to mix and ignite, thus repeating the cycle. In the motor shown in Plate 8, the explosion frequency is about 90 cycles per second. Other intake, chamber, and nozzle pipe sizes would cause this frequency to change. Plate 11 shows the dependence of the explosion frequency on the length of the air-intake pipe. Plates 2 to 7 show the effect on frequency of different chamber and nozzle-pipe sizes in various combinations.

METHOD OF TEST

10. Plate 12 shows the 6" Valveless-Resojet on its test stand. The motor is mounted on a rolling carriage which is allowed to move against an oil-filled thrust bellows, which, in turn, is connected to a pressure gauge. This oil pressure system is calibrated to allow direct reading of thrust while the Resojet is in operation.

11. Fuel (gaseous propane) is supplied to the Resojet from a pressure tank into which gaseous propane has been bled from its shipping container. From the gaseous propane tank, the fuel enters a manually-controlled fuel valve which is used to regulate the amount of fuel delivered to the motor. A spark plug, installed in th side of the motor, is connected in an slsctrical circuit with a Ford coil, and provides the initial ignition of the explosive charge.

12. When it is desired to make an efficiency run, the prssours and temperature of the gaseous propane in its tank are measured. An air blast from compressed air tanks is directed at the air intake pipe of the motor, its speed being measured by a pitot tubs mounted between the air sourcs and ths motor. The ignition system is turned on and the fusl valve opened, allowing gaseous propane to be fsd into the chamber by its own pressure in the supply tank. Combustion begins immediately at about 90 sxplosions psr sscond. The fuel flow is incrsased until ths thrust reaches a maximum. Any increase in fuel flow bsyond this pcint will cause the motor to stop running. The thrust, as measured by the thrust system prssaure gauge, is found to remain quite steady, since the high frequency of opsration produces effectively a constant thrust. The total time of ths run is measured by a stop watch. When the test run is ended, the pressurs and temperature of the gaseous propane in the supply tank are measured. Referencs to a Mollisr diagram for superhsated propane gas yields the total weight of propans consumed during the run.

RESULTS OF TEST

13. Plates 2 to 7 show ths results of all tests run on this type of motor. Plate 1 describes the best (from ths standpoint of efficiency) form tested. Results of tests on this particular motor are as follows:

Approx. Air speed MPH	Net thrust LBS	Specific thrust lbs/lbs/sec.
340	10.5	954
420	13.5	835
480	Would not resonate properly.	

14. It must be realized that no attempt was made in these tests to measure the extsrnal aerodynamic drag occasioned by the high air speeds, since air was supplied from a small duct and there was very little "spillover" from the air intaks pipe of the motor. The nst thrusts mentioned above and in Plates 2 to 7 do, however, include ths detrimental effect of internal air drag.

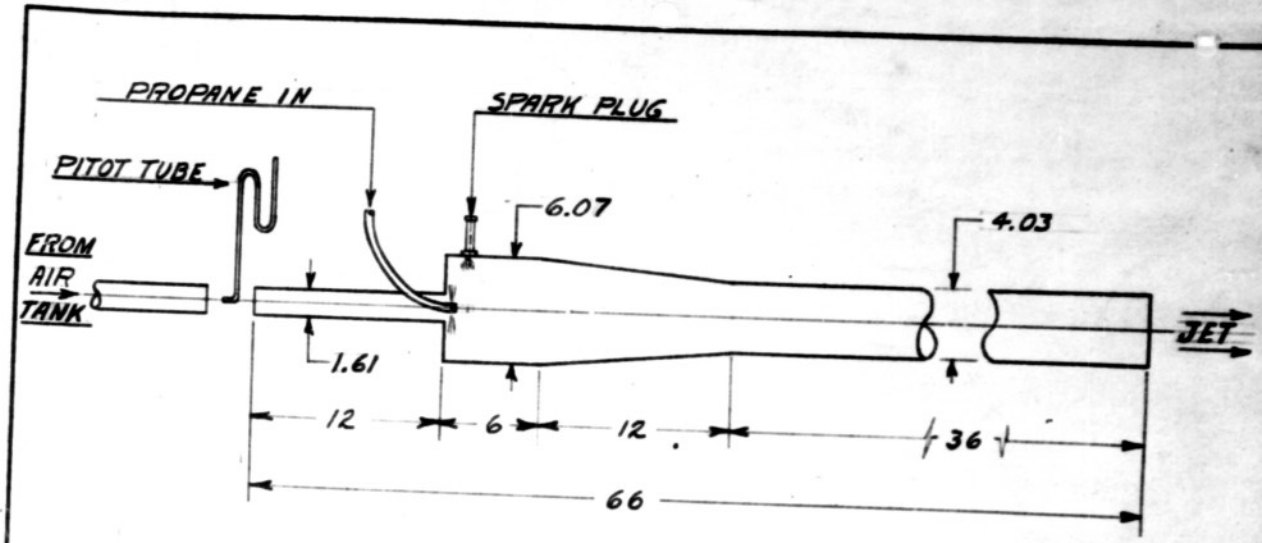
CONCLUSIONS

15. It is concluded, on ths basis of the forsgoing test results, that the Valveless-Resojet designed, constructed, and tested at this Station is capable of delivering a maximum net thrust of 13.5 lbs. at a specific thrust of 835, using gaseous propane as fuel. Conclusions, as to the effect of the external air drag on this motor's thrust and efficiency, cannot be

drawn, since no wind tunnel equipment was available for these tests. It is believed that the Valveless-Resojet in larger sizes, of course, could be useful in many applications which require a light-weight, expendable jet propulsion unit or a light-weight, compact gas generator for driving turbines, etc. Air pressure, of course, is required for this motor's operation, but would be readily available in applications to aircraft already travelling at high speeds.

RECOMMENDATIONS

16. It is recommended that work be continued on the Valveless-Resojet to improve its performance and usefulness.



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			DRAWN.				USED IN ASSEMBLY
			9/28/44	9/28/44	9/28/44	9/28/44	
MAT.	STOCK	QUAN.	DRAFTS	CHECKED	ENG	APPROVE	TEST SERIES-B5350
TOL. ± .010, 1/64 OR NOTED			SUPERSEDES DWG. NO.				CHANGE LETTERS
SCALE- 1/3 SIZE			SUPERSEDED BY DWG. NO.				
BUAER PROJECT T.E.D E.E.S.3401 U.S.N.E.E. STA. ANNAPOLIS, MD.			SCHEMATIC DIAGRAM 6" DIA. VALVELESS RESOJET				100953
			NAME				DRAWING NO.

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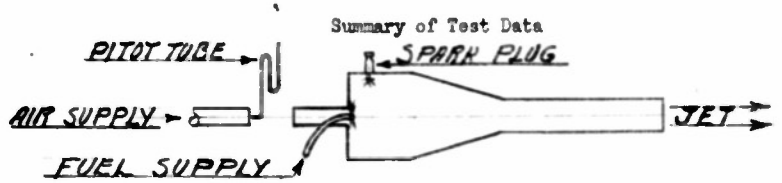
SERIAL NO. EES-B-5350-A8(N)

PLATE 1

Summary of Test Data



Motor				Fuel injection	Air speed	Net thrust	Time of run	Fuel flow	Specific thrust	Freq.
air intake pipe	combustion chamber	nozzle cone	nozzle pipe		mph	lbs	secs	lbs/sec	lbs T / lbs/sec	cyc/sec
d=2.5", l=12"	d=6",l=12"	l=6"	d=4" l=36"	at head end of chamber (see sketch)	240	8.5	-	-	-	-
"	"	"	"	"	340	13.5	-	-	-	-
"	"	"	"	"	420	16.5	-	-	-	-
"	"	"	"	"	340	12.5	127	.0205	610	-
"	"	"	"	"	"	"	95	.0159	787	-
"	"	"	"	"	"	13	56	.0187	697	-
"	"	"	"	"	"	13	155	.0195	665	-
"	"	"	"	"	200	9	131	.0124	725	-
"	"	"	"	"	340	14	73	.0198	708	-
"	"	"	"	"	420	17.5	93.5	.022	795	-
"	"	"	"	"	540	18	150	.0225	800	-
"	d=6, l=60	none	none	"	420	-	-	-	-	100
"	"	l=8	d=4 l=0	"	would not resonate					
"	"	"	d=4 l=36	"	340	5.5	90	.0248	222	-
"	"	"	"	"	420	12.5	60	.0309	405	-
"	d=6, l=12	l=6	"	"	240	7.5	124	.0122	615	-
"	d=10, l=12	"	"	"	"	6.5	-	-	-	-
"	"	"	"	"	340	7.5	-	-	-	-
"	"	"	"	"	420	12	-	-	-	-

Summary of Test Data (cont'd)

Motor				Fuel injection	Air speed	Net Thrust	Time of run	Fuel flow	Specific Thrust lbs T / lbs/sec	Freq. cyc/sec
air intake pipe	combustion chamber	nozzle cone	nozzle pipe		mph	lbs	secs	lbs/sec		
d=2.5", l=12"	d=10, l=12	l=6	l=23.5 d=4	at head end of chamber (see sketch)	240	5.5	-	-	-	-
"	"	"	"	"	340	9	-	-	-	-
"	d=6, l=12	"	d=4 l=36	mid-point air intake pipe	240	2	20.7	.0334	59.3	-
"	"	"	"	at head end of chamber	240	9.5	13	.0169	562	-
"	"	"	"	"	240	12.5	114	.0144	369	92
"	"	"	"	"	420	19	26	.0265	713	93.5
"	"	"	"	"	240	8	127.7	.0150	535	-
"	"	"	"	"	"	8	95	.01665	485	92
"	"	"	"	"	340	12.5	33.6	.0252	496	95
"	"	"	"	"	"	12	22.7	.0238	505	-
"	"	"	"	"	420	16	34.2	.0401	399	97.5
"	"	"	"	"	"	16.5	28.3	.0374	441	-
"	"	"	"	"	420	15.5	12.7	[illegible]	273	100
"	"	"	"	"	"	13.5	28	.0404	[illegible]	98
"	"	"	"	"	240	8	31.5	.01415	565	-
"	"	"	"	"	340	13	[illegible]	.023	565	-
"	"	"	"	"	420	17	[illegible]	.0318	535	-
"	"	"	"	"	420	17.5	32.4	[illegible]	[illegible]	-
d=2, l=12	"	"	"	"	240	8.5	55.3	.01285	662	-
"	"	"	"	"	340	12.5	47.4	.0186	673	-
"	"	"	"	"	420	17.5	53.4	.0279	627	-
"	"	"	"	"	430	21	32.7	[illegible]	394	-
d=1.5 l=12	"	"	"	"	240	6	54.7	.01025	585	-
"	"	"	"	"	420	16	[illegible]	.017	940	-

Summary of Test Data (cont'd)

Motor				Fuel injection	Air speed	Net thrust	Time of run	Fuel flow	Specific thrust $\frac{\text{lbs T}}{\text{lbs/sec}}$	Freq. cyc/sec
air intake pipe	combustion chamber	nozzle cone	nozzle pipe		mph	lbs	secs	lbs/sec		
d=1.5 l=12	d=6, l=12	l=6	d=4 l=36	at head end of chamber	480	16.5	39.8	.0249	663	-
"	"	"	"	"	240	7	62.2	.0084	835	83.4
"	"	"	"	"	340	12.5	53.7	.0134	935	-
"	"	"	"	"	420	16.5	57.8	.0173	955	-
d=1 l=12	"	"	"	"	340	6	85.2	.00764	786	85.7
"	"	"	"	"	420	7	96.4	.00943	743	-
d=2.5 l=12	"	"	"	"	340	12.5	47.4	.0266	470	-
"	"	"	"	"	420	15.5	27.1	.0306	506	-
d=1.5 l=12	"	"	"	"	240	6.5	94.9	.0075	867	-
"	"	"	"	"	340	11	61.7	.0128	860	-
"	"	"	"	"	420	16	53.6	.0159	1001	-
"	"	"	"	"	420	13	68.2	.0142	915	-
"	"	"	"	"	"	13	61.3	.0166	785	-
"	"	"	"	"	480	15.7	54.3	.0194	810	-
"	"	"	"	"	"	15.7	56.5	.0183	858	-
"	"	"	"	"	540	would not resonate properly				
d=1.5 l=18	"	"	"	"	340	10	58.1	.00825	1210	-
"	"	"	"	"	420	13	54.7	.0174	746	-
"	"	"	"	"	480	18 very erratic operation				
d=1.5 l=7	"	"	"	"	340	5.25	117.7	.00953	551	-
"	"	"	"	"	"	5.25	46.3	.0110	477	-
"	"	"	"	"	"	8.25	62.5	.0189	436	-
"	"	"	"	"	"	8.25	58.2	.0191	432	-
"	"	"	"	"	540	13.5	43.7	.0322	420	-
"	"	"	"	"	340	7	60.9	.01595	439	98.4

PAGE 4

Summary of Test Data (cont'd)

Motor				Fuel injection	Air speed	Net thrust	Time of run	Fuel flow	Specific thrust $\frac{\text{lbs T}}{\text{lbs/sec}}$	Freq. cyc/sec
air intake pipe	combustion chamber	nozzle cone	nozzle pipe		mph	lbs	secs	lbs/sec		
d=1.5 l=7	d=6, l=12	l=6	d=4 l=36	at head end of chamber	340	7.7	62.4	.01830	421	-
"	"	"	"	"	420	10.25	52.9	.02330	440	-
"	"	"	"	"	480	13.5	55.8	.0299	452	-
d=1.5 l=8	"	"	"	"	340	8.0	58.3	.0163	491	92
"	"	"	"	"	"	8.5	56.8	.0167	509	-
d=1.5 l=9	"	"	"	"	"	9	55.0	.014	644	90
"	"	"	"	"	"	8.5	62.2	.0143	595	-
d=1.5 l=10	"	"	"	"	"	8.5	62.4	.0125	680	88.5
"	"	"	"	"	"	8.5	61.8	.01248	682	-
d=1.5 l=11	"	"	"	"	"	8.7	62.0	.0111	785	87.5
"	"	"	"	"	"	9	61.7	.0110	817	-
d=1.5 l=11.3	"	"	"	"	"	9.0	61.5	.0134	953	87
"	"	"	"	"	"	8.5	62.0	.00952	998	-
d=1.5 l=11.5	"	"	"	"	"	8.5	62.4	.00995	955	85
"	"	"	"	"	"	9.0	63.1	.0101	892	-
d=1.5 l=11.5	"	"	"	"	"	8.5	62.2	.0108	880	86.5
"	"	"	"	"	"	9.0	62.2	.0103	875	-
d=1.5 l=12.63	"	"	"	"	"	8.5	62.1	.0111	855	87
"	"	"	"	"	"	9.2	64.9	.0117	785	-
"	"	"	"	"	"	8.5	61.8	.011	865	-
d=1.5 l=12	"	"	"	"	"	10	63	.0128	780	-
				mid-point air intake pipe	"	9.0	63.2	.0163	553	85

Summary of Test Data (cont'd)

Motor				Fuel injection	Air speed	Net thrust	Time of run	Fuel flow	Specific thrust $\frac{\text{lbs T}}{\text{lbs/sec}}$	Freq. cyc/sec
air intake pipe	combustion chamber	nozzle cone	nozzle pipe		mph	lbs	secs	lbs/sec		
d=1.5 l=12	d=6, l=12	l=6	d=4 l=36	mid-point air intake pipe	340	9.0	62.2	.0163	553	-
"	"	"	"	at head end of chamber	"	9.5	63.0	.0102	930	97.5
"	"	"	"	"	"	10.0	60.9	.0125	800	-
"	"	"	"	"	"	10.2	60.7	.0119	856	-
"	"	"	"	"	"	9.5	66.3	.0112	850	-
"	"	"	"	"	"	9.2	63.3	.0106	859	-
"	d=6, l=11	"	"	"	"	8.6	66.7	.0108	790	-
"	"	"	"	"	"	8.5	67.6	.0110	773	-
"	d=6, l=6	"	"	"	"	9.0	62.1	.00965	935	100
"	"	"	"	"	"	9.2	62.0	.0105	880	-
"	"	"	d=4 l=18	"	would not resonate properly, intermittent explosions at about 15/sec.					
"	"	l=12	"	"	would not resonate properly					
"	"	"	d=4 l=27	"	340	10	62.7	.0113	885	105
"	"	"	"	"	"	10	62.3	.0116	862	-
"	"	"	d=4 l=36	"	"	10.6	62.7	.0123	855	90
"	"	"	"	"	"	10.3	62.9	.01075	960	-
"	"	"	"	"	320	13.5	61.9	.0170	795	-
"	"	l=9.5	d=4.5 l=36	"	340	10.5	60.3	.0101	934	-
"	"	"	"	"	320	9.7	61.7	.0107	908	-
"	"	"	d=4.5 l=27	"	340	10.5	62.5	.0099	874	-
"	"	"	"	"	320	would not resonate properly				
"	"	"	d=4.5 l=18	"	would not resonate properly					
"	"	l=6	d=4 l=36	"	320	11.7	would not resonate properly			
"	"	l=12	"	"	340	10.0	70.6	.0107	1090	-

PLATE 6

Summary of Test Data (cont'd)

Motor				Fuel injection	Air speed mph	Net thrust lbs	Time of run secs	Fuel flow lbs/sec	Specific thrust lbs T / lbs/sec	Freq. cyc/sec
air intake i.d.	combustion chamber	nozzle cone	nozzle pipe							
d=1.6 l=12	d=7, l=6	l=12	d=4 l=36	at head end of chamber	340	10.3	62.5	.0101	1020	-
"	"	"	d=4 l=29.8	"	"	10	63.3	.0107	935	98.5
"	"	"	"	"	"	10	65.3	.0118	850	-
"	"	"	d=4 l=24	"	"	8.7	61.7	.0141	617	117
"	"	"	d=4 l=12	"	would not resonate properly					
"	"	"	d=4 l=42	"	340	9.7	62.5	.01185	820	81
"	"	"	"	"	"	10	62	.01225	815	-
"	"	"	d=4 l=42	"	"	10	62.2	.014	714	81
"	"	"	"	"	"	10	62.1	.0143	700	-
"	"	"	d=4 l=36	"	"	10.5	62	.01145	915	88.5
"	"	"	"	"	420	13.5	61.9	.0154	875	88.5
"	"	"	"	"	420	would not resonate properly				
d=5 l=12	d=8, l=8	l=12	d=5 l=42	"	340	19	48	.0198	960	66.6
"	"	"	"	"	420	25	52.1	.0278	900	66.6
"	"	"	d=5 l=36	"	340	19	44.5	.020	950	75
"	"	"	d=5 l=24	"	"	16	61.5	.0244	656	97
"	"	"	d=5 l=36	"	"	18.5	62	.0192	965	75

PLATE 7

PLATE 8

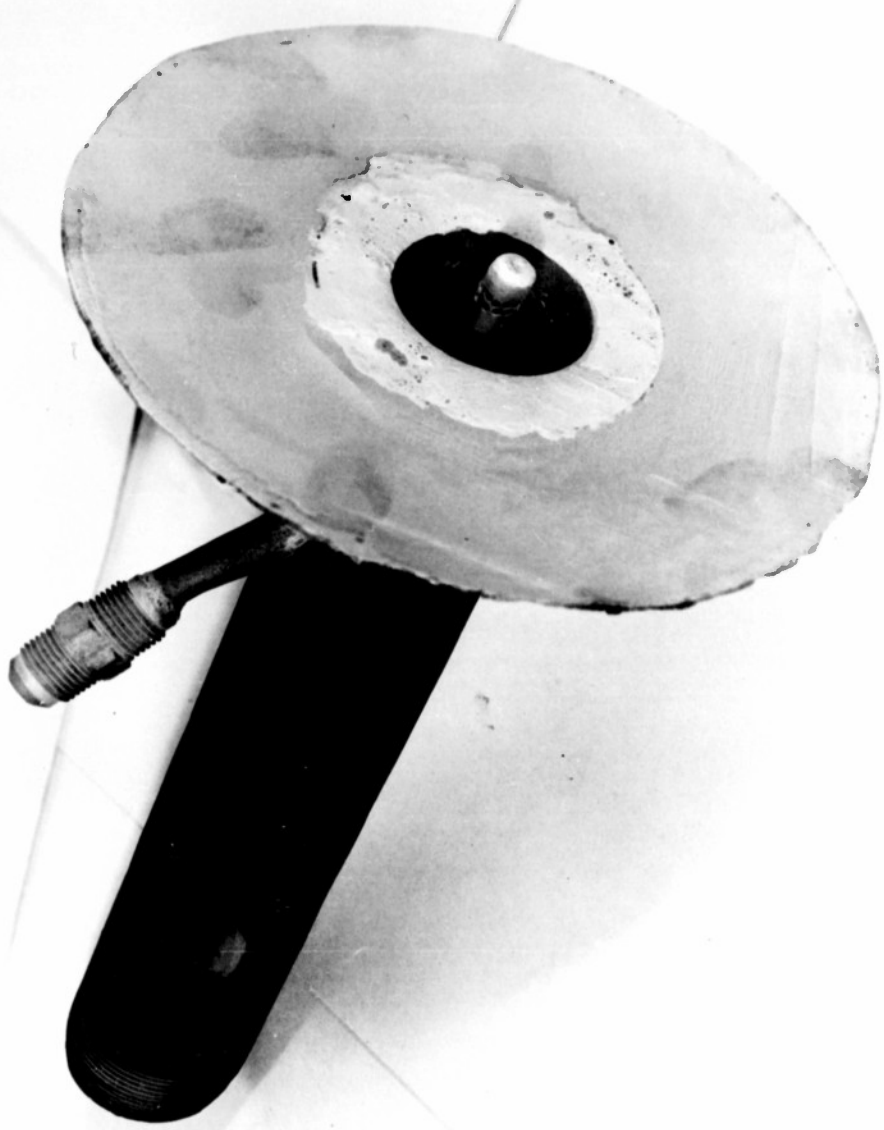


PLATE 9

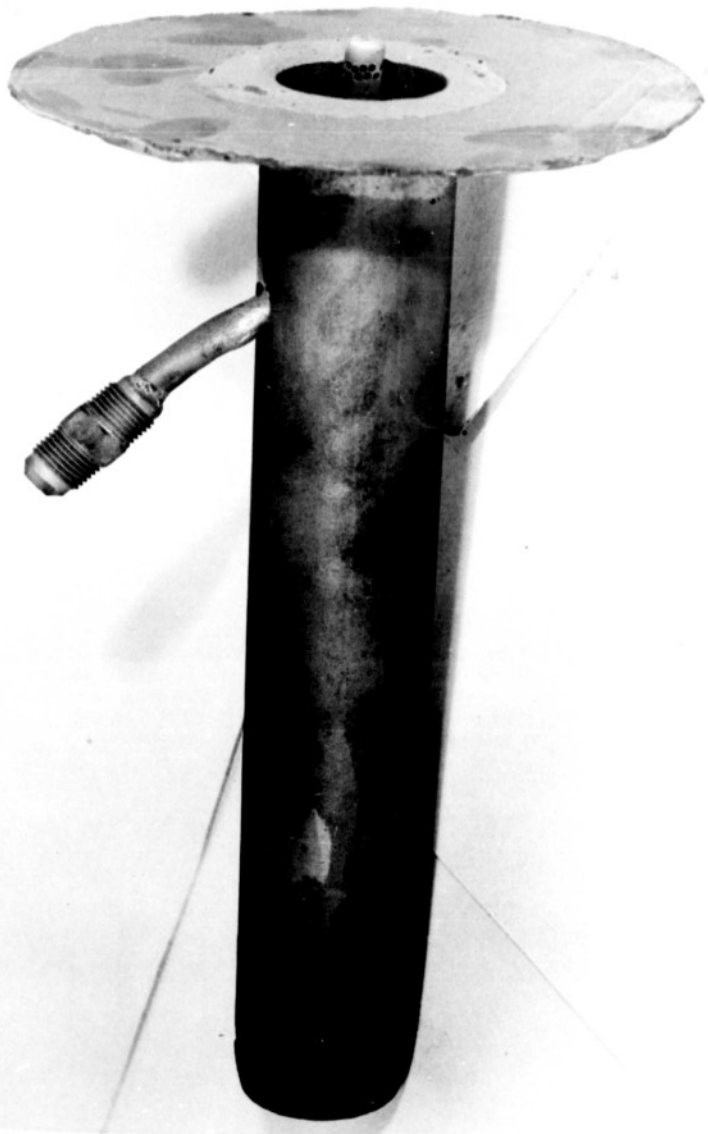


PLATE 10

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SERIAL NO. EES-B-5350-AS(b)

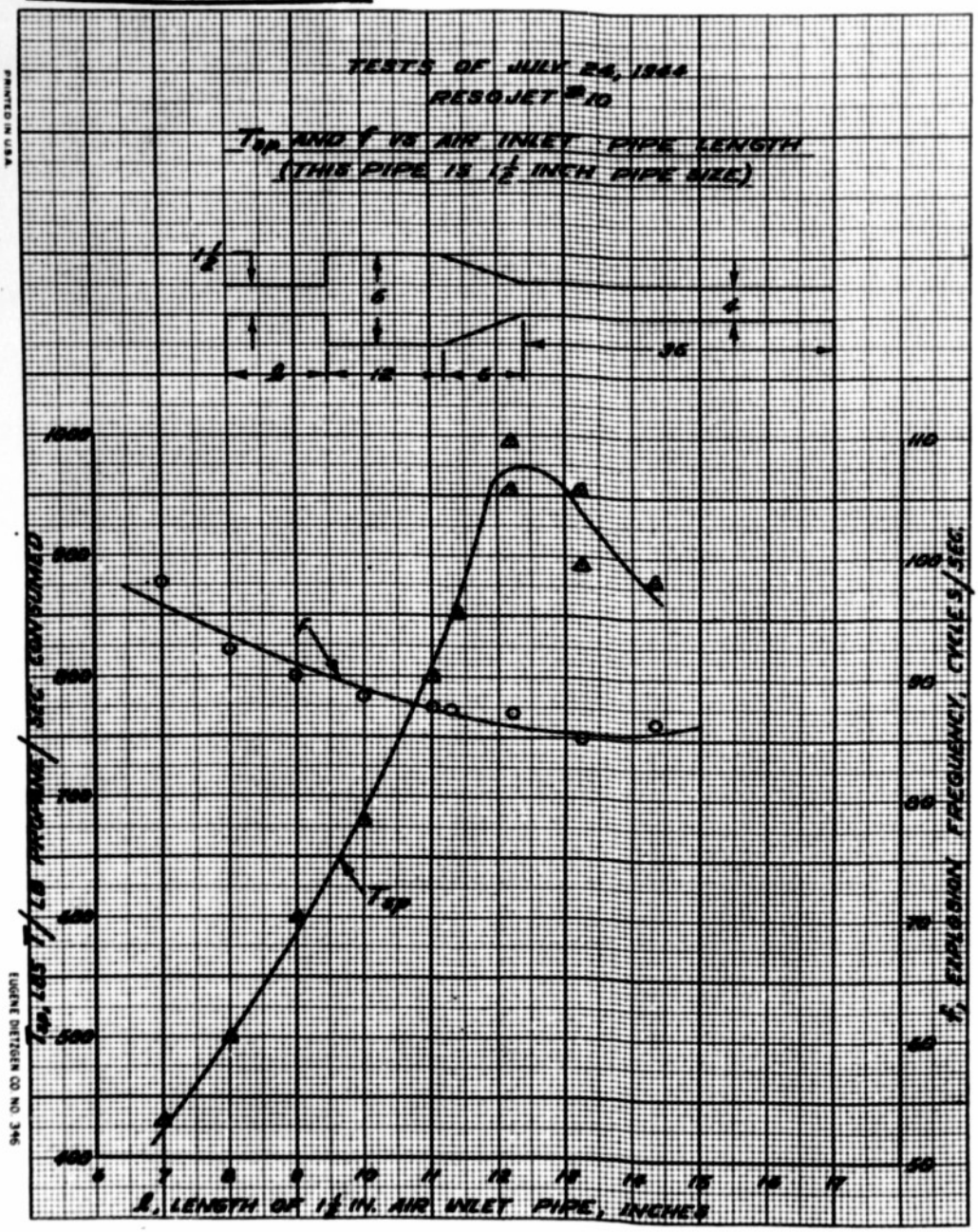

PLATE 11

PLATE 12

REEL — C

412

A.T.I.

12548

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AUTHOR(S)

C-5-17-3

DIVISION: Power Plants, Jet and Turbine (5)
SECTION: Testing (17)
CROSS REFERENCES: Engines, Jet propulsion - Pulse jet (33400); Engines - Design (32864); Generators, Gas (45475)

AMER. TITLE: Design, construction, and testing of a 6" valveless-resojet

FORG'N. TITLE: PZL-5 [illegible] Engine

ORIGINATING AGENCY: Navy Dept., Bureau of Aeronautics, Annapolis, Md.

TRANSLATION:

(OVER)

COUNTRY	LANGUAGE	FORG'N CLASS	U. S. CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		~~Confdl~~	Jun'44	18	7	photos, tables, graph, drwgs

ABSTRACT

Six in. valveless-resojet engine was designed, constructed, and tested. Power plant consists of combustion chamber, nozzle pipe, air intake duct, end a means of injecting end igniting fuel. Valving is accomplished acoustically rather than mechanically. Gaseous propane was used as fuel. This power plant is capable of delivering a maximum net thrust of 13.5 lb at specific thrust of 835 lb/lb/sec. Engine could be used in applications which require a light-weight, jet-propelled unit or as gas generator for driving turbines.

Auth: DoD Dir 5200.9, 27 Sep 58
(RBio. 114)